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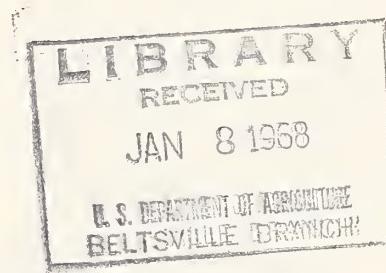
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REPAIR OF CRACKS IN CONCRETE CHANNEL LININGS



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REPAIR OF CRACKS IN CONCRETE CHANNEL LININGS¹

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INTRODUCTION

Water loss from concrete-lined canals and storage structures normally occurs through cracks in the concrete. Only negligible quantities of water can move through properly formulated concrete of reasonable quality.

To answer questions concerning the possible movement of water through thin, gunite concrete linings, the authors obtained 2-inch-diameter cores from canal linings in the Salt River Valley in Arizona. Cores were taken from three different linings ranging in age from 8 to 27 years. When subjected to 3 ft. of hydraulic head, the movement of water through these cores was essentially zero.

This test agrees with the findings of Withey (8)³ and of Tyler and Erlin (5). The permeability of concrete as measured by Withey was 1×10^{-5} ft./day/in. concrete/ft. head. The highest value of concrete permeability obtained by Tyler and Erlin was 2.5×10^{-4} ft./day/in. concrete/ft. head. These data indicate that the loss of 0.05 cu. ft./sq. ft. of wetted perimeter/24 hrs., which is listed as a reasonable loss from a properly constructed and maintained concrete-lined canal (6), still consists primarily of seepage through cracks in the concrete. The magnitude of losses that can occur through cracked, concrete linings is illustrated by measurements on the gunite-lined South Canal of the Salt River Project in Arizona (4). Prior to repair, seepage losses from this badly cracked concrete amounted to about 2,800 acre-ft. of water per mile of canal per year. This is probably a maximum loss that would be encountered. The value of the water lost at \$3 per acre-foot amounted to \$8,400 per mile per year.

Cracks cause progressive deterioration of concrete canal linings in addition to problems of water loss, waterlogging of lower lands, and heaving or settling of canal subgrades. Temperature changes cause cracks in concrete linings to open and close on a daily cycle. Burns⁴ has stated that cracks widen and that linings continue to deteriorate because of "...the constant grinding and spalling of the edges of the crack as it opens and closes on the silt deposits which are washed into it." Such deterioration of linings can be prevented by applying flexible surface seals over the cracks while they are still small.

The magnitude of concrete crack movement was measured on a 2-in.-thick, concrete-lined farm ditch with a wetted perimeter of about 9 ft. Measurements were made in May 1963 near Phoenix, Ariz., by cementing pieces of machined angle iron on each side of the cracks and periodically measuring the distance between angles with gage blocks and a micrometer. Surface temperature of the concrete was measured with a small thermistor. The ditch ran east and west, the cracks were transverse, and there was a distance of approximately 14 ft. between cracks. Cracks with a northern exposure were closed at concrete surface temperatures above 75° F. and cracks with a southern exposure were closed at temperatures above 85°. At temperatures below

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³ Underscored numbers in parentheses refer to Literature Cited at end of this publication.

⁴ F. L. Burns, Unpublished information.

those where the cracks were closed, the opening of the crack could be calculated almost exactly by using the concrete surface temperature and a thermal expansion coefficient of 6×10^{-6} in./in./degree F. The maximum wintertime crack opening on the measured ditch would be approximately 0.06 in. near Phoenix, where the minimum wintertime temperature is 16°. Near Billings, Mont., where the minimum temperature is -49°, the maximum wintertime opening of similar cracks would be approximately 0.13 in. Daily crack movement, caused by the difference between day and night temperatures, would be only a fraction of the maximum crack opening. These figures indicate the distance a satisfactory crack sealer must stretch without rupturing.

Commonly used methods for the repair of cracks in concrete hydraulic structures involve laborious and expensive concrete cleaning procedures and the hand application of sealing materials. Cleaning procedures have included hand brushing, sand blasting, and air jets. Sealants have usually been mastics which were hand-troweled into and over cracks and joints. These mastic sealants are essentially crack fillers and cannot be used on small cracks. It is often necessary to enlarge cracks by chiseling to permit filling them with mastic sealer (7). Burns (1) used a crack sealer in 1959 that was intended to cover cracks rather than fill them. This consisted of a neoprene material which was dissolved in solvent and applied by hand brushing. It was necessary to apply four or five coats to obtain adequate coverage. Concrete treated by Burns was cleaned by hand brushing. The time, labor, and expense involved in these commonly used methods of crack sealing have discouraged the maintenance and repair of cracks in concrete linings. In December 1964, Houston (3) stated that "... an entirely satisfactory material for filling and sealing cracks has not been developed to date." Effective, rapid, and less expensive methods of crack sealing are badly needed.

In 1963 a project was initiated to develop improved methods and materials for sealing cracks in concrete hydraulic structures. Asphalt, modified to obtain the desired properties, was selected as the basic sealant material to reduce costs. It was similarly decided that costs for cleaning and application would be lowest with power spray equipment. At the time the project was initiated, the authors were unable to obtain a commercially available, sprayable crack sealer. Experimental results are described in this paper.

SEALING MATERIALS

Asphalt emulsion was used as the base material in the formulation of a sprayable crack sealer. Improved extensibility and weathering resistance were obtained by the addition of butyl latex. Asbestos fibers were added to reduce running or slumping of the asphalt on steep slopes. All of these materials are readily available and are classed as nontoxic. Formulation of the crack sealers consisted of combining various amounts of asphalt emulsion, butyl latex, and asbestos fibers. Formulation did not appear critical but there were certain limits. Increasing the amount of butyl latex increased material costs and caused clogging problems with the piston-pump spray equipment first used in this project; too much asbestos also caused clogging. From preliminary laboratory and field observations of the physical properties and spraying characteristics of these mixtures, it was decided that formulations containing approximately 48 percent asphalt, 3 percent actual butyl latex, 14 percent asbestos fibers, and 35 percent water would be reasonably satisfactory. Shortly after the initial testing of laboratory-mixed materials, a commercial sprayable crack sealer became available.

Bonding of pure asphalt to concrete is ordinarily a mechanical process. Adhesion is often poor and the asphalt can be mechanically stripped or peeled from the concrete. The asphalt in the two sprayable sealants used in these tests had been modified by adding cationic antistripping agents. Concrete normally has a negatively charged surface. The addition of cationic anti-stripping agents to the emulsion causes the asphalt to act as a positively charged material. This creates an electrochemical bond of the treated asphalt to the concrete surface (2). Such bonding will take place in the presence of water.

Bonding of asphalt to concrete can be improved by the addition of rubber or other materials to increase the tack or stickiness of the asphalt mixture. Two nonsprayable rubberized-asphalt mastics, sold commercially for repairing cracks in concrete, were included in the laboratory tests for comparison with the sprayable sealers.

LABORATORY TESTS

The bonding of four crack sealers to concrete was evaluated in the laboratory. Tested sealants included a laboratory-mixed sprayable material, S_1 , a commercially available sprayable material, S_2 , and two commercially available rubberized asphalt mastics, M_1 and M_2 . Measurements were made in an attempt to determine differences in bonding caused by variations in concrete cleaning, tack coat applications, temperature, and curing time.

Testing procedure consisted of pulling apart two concrete blocks, $2 \times 2 \times 1$ in. in size, which had been bonded with a 0.05-in. layer of crack sealer between the 1×2 in. surfaces. Block surfaces treated included concrete with a 0.05-in. layer of mud on the surface, concrete with mud lightly brushed off, and new, clean concrete. In addition to cleaning, at the time of crack-sealer application the concrete surfaces were either dry, wet with water, or brushed with a tack coat of kerosene that contained a surfactant. After application with a putty knife, the sealing materials were allowed to cure for periods of 1, 7, and 28 days at a temperature of 77° F. and a relative humidity of 40 percent.

The blocks were then pulled apart at a rate of 0.25 in./min. in a laboratory testing machine located in a controlled temperature room. Bonding of dry surface samples was tested at 50° , 77° , and 104° . Bonding of tack and wet surfaces was checked only at 77° . Only 1 and 7 days' curing times were used to test the bonding of sealers to wet concrete surfaces. All treatment variations were triplicated. After being pulled apart, the blocks were inspected visually to determine any bonding failures. Results are presented in table 1. Bond was considered good if both concrete surfaces were completely covered with sealing material when pulled apart. Bond was considered fair if sealant had pulled free from only one or two small spots, and poor if a greater amount of bare concrete was visible.

TABLE 1.--Bonding of four crack sealers¹ to concrete as affected by curing time, surface pretreatment, temperature, and cleanliness of concrete.

Cure time	Surface	Temp. ^o F.	Clean ²				Brushed concrete ²				Mud ²			
			S_1	S_2	M_1	M_2	S_1	S_2	M_1	M_2	S_1	S_2	M_1	M_2
Days	1	Tack	G	G	G	G	G	G	F	F	P	P	P	P
		77	G	G	G	G	F	G	-	-	-	-	-	-
		50	G	G	G	G	G	G	P	P	P	P	P	P
		77	G	G	G	G	G	G	-	-	-	-	-	-
		104	G	G	G	G	G	G	-	-	-	-	-	-
	7	Wet	G	G	G	G	-	-	-	-	-	-	-	-
		77	P	F	P	P	P	F	P	P	P	P	P	P
		77	P	P	F	G	P	P	F	G	-	-	-	-
		50	G	G	G	G	G	G	G	G	P	P	P	P
		77	G	G	G	G	F	G	F	G	-	-	-	-
	28	Dry	G	G	G	G	-	-	-	-	-	-	-	-
		104	G	G	G	G	G	G	G	G	-	-	-	-
		77	G	G	G	G	P	P	P	P	-	-	-	-
		50	G	G	G	G	G	G	F	G	-	-	-	-
		77	G	G	G	G	F	G	P	G	-	-	-	-

¹ S_1 --a laboratory-mixed sprayable material; S_2 --a commercially available sprayable material; M_1 and M_2 --commercially available rubberized asphalt mastics.

² Bond: G = Good, no exposed concrete, F = fair, small spot or two of exposed concrete, and P = poor, appreciable exposed concrete.

General conclusions from the laboratory tests are: (1) All four sealants bonded very well to clean concrete, either wet or dry, at all temperatures; (2) no sealant bonded to muddy concrete; (3) bonding to brushed concrete after 28 days' curing was fair to good for S₁, S₂ and M₂ at temperatures above 50° F., but all bonds failed at 50°; (4) at 7 days' curing time a kerosene tack coat reduced bonding to clean concrete and did not improve bonding to brushed concrete, but at 28 days' curing time, the bond to clean concrete was not reduced and the bond to brushed concrete was apparently improved.

Durability and ductility of the crack sealers were not studied in the laboratory. A field evaluation of these factors was initiated for the sprayable sealers by applying them to cracks in the concrete linings of operational ditches and canals.

FIELD APPLICATIONS

In May 1964 a field test was initiated to determine the sprayability of the crack sealers, the concrete cleanliness needed, and the necessity for a tack coat. Three sealers were applied to joints and cracks in the same field ditch where crack movement had been measured. The joints and cracks had either been swept with a bristle broom or thoroughly cleaned with a wire brush. Half were then sprayed with a tack coat of cutback asphalt and half left without a tack coat. The sealers applied were S₁ and S₂, and a clay-type asphalt emulsion modified with butyl latex and asbestos fibers. Sealers were sprayed on the cracks and joints with a high-pressure (2,500 p.s.i.) piston pump driven by compressed air. The pump unit functioned properly if spraying was continuous. Intermittent spraying caused all three sealers to break down in the pump, forming solid lumps that stopped the equipment.

In January 1965, silt deposited from irrigation water was removed from the bottom of the ditch with shovels with no damage to the test materials. All materials bonded tightly to the concrete, regardless of whether a tack coat was applied or whether the concrete was wire brushed or merely swept clean.

In October 1965, inspection of all field sites 17 months after treatment, revealed that S₁ and S₂ crack sealers generally were weathering well, with S₂ remaining slightly more pliable. Both sealers had cracked slightly on about half the south-facing cracks. However, there was little cracking of the sealers placed on the north-facing slope. The crack sealer with the asphalt-clay emulsion had hardened and cracked on both sides of the ditch. All three materials, regardless of concrete cleanliness, were bonded tightly and could not be peeled with a knife. It should be pointed out that this field ditch carried water only intermittently and the crack sealers were exposed to air and sunlight for almost all of the 17-month period. Mastic sealer M₁ cracked and peeled from the concrete after 1 year of exposure in this same farm ditch.

In November 1965, a 500-ft. section of the Tempe Canal in the Salt River Valley, Arizona, which is gunite-lined on one side for erosion control, was treated with the commercial sealer S₂. Air temperature at treatment time was 50° F. This material was sprayed with the piston pump on cracks in the paved canal side which has a 1:1 slope and a vertical height of 7 ft. Some cracks had received a tack coat of kerosene and surfactant. Some had been swept clean, some wire brushed, and some washed clean with a high-pressure water jet.

The cracks were cleaned with water using a 400 to 500 p.s.i. jet from a commercially available pump and sprayer unit usually used for applying insecticides to trees and orchards (Model 10-T, Thuron Sprayer Mfg. Co.). The small multiple-piston water pump, driven by a 7-1/2 hp. gasoline motor, is attached to a 300-gal. tank mounted on a trailer. The pump has a capacity of 10 gal./min., and with the proper size orifice in the nozzle, pressures up to 500 p.s.i. are attainable. The high-pressure water jet blasted the soil out of the cracks and rapidly removed all silt and algae deposited around the edge of the cracks. Fine cracks, covered and hidden by silt and algae, could be quickly uncovered and traced out with the water jet. It also washed the soil away from the crack area so that the sealer could be sprayed directly on the clean, wet concrete.

The high-pressure water jet is much faster than handcleaning with a wire brush or even sand blasting; the latter method requires removal of the sand from the crack area.

About 800 ft. of cracks were covered with 40 gal. of S₂ sealer. Cost of the material given by the manufacturer is about \$1.50 per gal. depending on volume. The sealer did not run on the steep sideslope even though layers of material up to 1/4 in. thick were sprayed over some cracks. The Tempe Canal was inspected in November 1965. There was no visual difference between treatments above the waterline; all remained pliable and tightly bonded to the concrete. Regardless of the cleanliness of the concrete surface, it was impossible to scrape the sealer from the concrete with a knife. The sealer on most of the cracks had started to check slightly above the waterline. Below the waterline there was no checking visible on any of the treatments. However, on the cracks that had been brushed clean and had not received a tack coat, the sealer had started to peel from the concrete. Material sprayed on cracks brushed clean and primed with tack coat was bonded tightly to the concrete. Where the sealer was sprayed on the cracks cleaned with the water jet, there were no bonding failures and the sealer could not be separated from the concrete.

Since the Tempe Canal installation, a new type of high-pressure (1,500 p.s.i.) diaphragm pump has been obtained for spraying crack sealers (P-series pumps, PCP Corp.). This pump is driven by a small, integrally mounted 2 1/4-hp. gasoline motor and requires no supplemental air compressor. Two men can easily lift the pump. The diaphragm pump creates less shearing action on the sealer than did the previously used piston pump and does not cause the sealer to break down within the spraying equipment. A section of farm-sized concrete-lined ditch near Tempe, Ariz., was treated with the S₂ crack sealer in August 1965. No clogging problems were encountered while spraying the S₂ sealer. About 800 ft. of cracks were sprayed with 10 gal. of sealer in an hour.

Sealing cracks with power spray equipment requires three men: One to clean the cracks with the water jet, one to spray the crack-sealing material, and one to drive the equipment truck. Cost of the spray equipment, excluding the truck, is about \$2,000.

Investigations reported by Wallace (7) have shown that after 5 years of exposure in an operational canal, rubberized-asphalt compounds were keeping joints sealed better and were remaining more resilient than five other general types of crack-sealing materials. Experimental material S₁ and developmental material S₂, which were slightly checked after 17 months of exposure to sun and air in the field, are sprayable, rubberized-asphalt type sealers. Manufacturers should be able to improve the durability of sprayable crack sealers, at slightly increased cost, to equal that of the mastics.

CONCLUSIONS

A method for the rapid repair of cracks in concrete-lined channels utilizing commercial power equipment has been developed. Based on this work, the following conclusions are presented:

1. Cracks in a silt- and algae-encrusted concrete lining can be rapidly and effectively located and cleaned with a high-pressure water jet.

2. Materials to seal cracks by covering or filling can be applied rapidly and effectively with high-pressure spray equipment.

3. The sprayable and mastic-type crack sealers used in this study bonded tightly to wet, clean concrete and can be applied immediately after the concrete is cleaned with a water jet.

4. Sealers applied by high-pressure spray in the field bonded tightly to concrete cleaned with a high-pressure water jet or brushed clean and primed with a tack coat, but did not bond tightly to concrete that was only brushed clean. The same sealers also bonded poorly to slightly dirty concrete when applied with a putty knife in laboratory tests.

5. Tack coats of kerosene and cutback asphalt improved bonding of sealants to brushed clean concrete in 1-year-old field tests, although laboratory tests showed that tack coats may have deleterious effects on initial bonding.

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